Electrostatic Evaluation

SCAPE Suit Materials

ESPL-TR05-005

Date: July 21, 2005

Electrostatics and Surface Physics Laboratory

NASA
YA-C2-T

Table of Contents

1.0 Surface and Volume Resistivity Tests

The initial series of tests performed to evaluate the electrostatic properties of materials is surface resistivity. Surface resistance measurements are the main test method used in industry to characterize the ESD properties of materials, since it is believed that charge deposited onto the surface of a material will "leave" (or decay) easier from a material with lower surface resistance than from a material with high surface resistance. Materials with a surface resistance less than $10^4\ \Omega$ are considered conductive. Materials between $10^4\ \Omega$ and $10^{11}\ \Omega$ are statically dissipative and materials with a surface resistance above $10^{11}\ \Omega$ are insulating according to ANSI/ESD standards*.

Surface resistance is the ratio of the DC voltage to the current flowing between two electrodes of specified configuration that contact the same side of the material and is expressed in ohms (Ω). The surface resistivity tests are performed per the requirements of the ESD Association Standard Test Method ESD STM11.11*. These measurements are taken using a PRS-801 resistance system with an Electro Tech System (ETS) PRF-911 concentric ring resistance probe. The tests require a five pound weight on top of cylindrical electrodes and were conducted at both ambient and low humidity conditions. In order for materials to "pass" resistivity tests the surface of the materials must either be conductive or statically dissipative otherwise the materials "fail" ESD.

Volume resistivity tests are also conducted to measure conductivity through the material as opposed to conductivity along the surface. These tests are conducted using the same PRS-801 resistance system with the Electro Tech System PRF-911 concentric ring resistance probe but are performed in accordance with ESD Association Standard Test Method ESD STM11.12**.

Several materials were given to the ESPL for testing:

1. Trellchem VPS Type TE (yellow material)
2. Trellchem HPS Type TE (red material)
3. Respirex material
4. Reeves material (current SCAPE suit material)
5. Reeves material with Staticide and Dawn as an additive
6. Reeves material with Staticide and IPA solution as an additive
7. Saint Gobain (PTFE coated fabric material)
8. Boot
9. Glove

*ESD Association Standard Test Method ESD STM11.11, "Surface Resistance Measurements of Static Dissipative Planar Materials", (2001).

**ESD Association Standard Test Method ESD STM11.12, "Volume Resistivity Measurements of Static Dissipative Planar Materials", (2001).

1.1 Surface Resistivity Results

The data below is from ten 5" × 5" test specimens cut from each fabric and tested per ESD STM11.11-2001 – 12 ± 3% Relative Humidity and 23 ± 3° C. Second round of tests were performed at 45% RH (room humidity).

(Note: MΩ is mega ohms 10^6 Ω, GΩ is giga ohms 10^9 Ω, and TΩ is tera ohms 10^{12} Ω)

a. Trellchem VPS Type TE

12% RH

Item	ρ_s (Yellow side, GΩ)	ρ_s (White side, GΩ)
Average:	170.9	418.8
Max:	212	1700
Min:	135	221

45% RH

Item	ρ_s (Yellow side, GΩ)	ρ_s (White side, GΩ)
Average:	242.2	675.2
Max:	430	1570
Min:	141	345

Both sides of the fabric are **insulative** at both humidity points.

b. Trellchem HPS Type TE

12% RH

Item	ρ_s (Red side, TΩ)	ρ_s (White side, TΩ)
Average:	5.302	1.337
Max:	18.5	10.0
Min:	1.04	1.03

45% RH

Item	ρ_s (Red side, GΩ)	ρ_s (White side, TΩ)
Average:	558	2.629
Max:	807	12.9
Min:	280	0.219

Both sides of the fabric are **insulative** at 12% RH and 45% RH.

c. Reeves SCAPE Suit Fabric

12% RH

Item	ρ_s (Tan side, TΩ)	ρ_s (Gray side, TΩ)
Average:	10.87	16.75
Max:	19.2	28.5
Min:	4.29	11.6

45% RH

Item	ρ_s (Tan side, TΩ)	ρ_s (Gray side, TΩ)
Average:	3.847	3.725
Max:	11.4	6.6
Min:	1.13	0.248

Fabric is **insulative** on both sides for both humidity points.

d. Respirex SCAPE Suit Fabric

12% RH

Item	ρ_s (Tan side, TΩ)	ρ_s (Gray side, TΩ)
Average:	1.969	2.619
Max:	4.47	3.9
Min:	1.18	1.14

45% RH

Item	ρ_s (Tan side, TΩ)	ρ_s (Gray side, TΩ)
Average:	3.51	4.24
Max:	5.13	13.2
Min:	2.6	2.25

Fabric is **insulative** on both sides for both humidity points.

e. Saint-Gobain Fabric

Tests performed on the Saint Gobain materials were conducted on one side only since the materials are homogeneous.

12% RH

Item	ρ_s (TΩ)
Average:	1.82
Max:	2.12
Min:	1.42

45% RH

Item	ρ_s (GΩ)
Average:	365.5
Max:	630
Min:	246

Fabric is **insulative** for both humidity points.

f. SCAPE Suit Boot & Glove

Boot

Tests performed at room humidity (~ 45% RH). Surface Resistance data is an average of four tests per location on the boot as shown below in the figure.

Location	ρ_s (GΩ)
1	2.11
2	1.48
3	2.18
4	5.315
5	2.59
6	700

Boot is **static dissipative** at all locations tested except for location 6 (top band) which is **insulative**.

Glove

Tests performed at room humidity (~ 45% RH). Surface Resistance data is an average of four tests per location on the glove as shown in the figure below. Each location was chosen because of the different surface textures or materials in those areas.

Location	ρ_s
1	41.53 MΩ
2	1.08 MΩ
3	4.73 TΩ

Glove is **conductive** at locations 1 and 2 but is **insulative** at location 3 (cuff band).

1.2 Resistance Measurements of Conductive Thread

Three samples with different configurations of conductive thread were tested for resistance between two contact points. The conductive threads used are conductive filaments manufactured by Shakespeare Conductive Fibers. Sample one had a bundle of fibers connecting two bolts. Sample two was a bundle of fibers connecting two snaps. Sample three had a mixture of chopped fibers and butyl adhesive applied in a strip connecting two bolts. Each of the three configurations were applied to the gray side of the Reeves SCAPE suit material using butyl adhesive.

Each sample was tested 10 times with the PRS-801 resistance meter in room humidity (~50% RH). The following table is a summary of these resistance measurements.

Configuration	Ave. Resistance (Ω)
Bundle of fibers with bolts	447 E+3
Bundle of fibers with snaps	304.5 E+3
Chopped fibers with bolts	1.52 E+12

1.3 Volume Resistivity Tests

The data below is from 10 5" × 5" test specimens cut from each fabric and tested per ESD STM11.12-2001 – 12 ± 3% Relative Humidity and 23 ± 3° C. Second round of tests were performed at 45% RH (room humidity).

a. Trellchem VPS Type TE

12% RH

Item	ρYellow side, GΩ-cm)	ρWhite side, GΩ-cm)
Average:	7.32 E+3	4.15E+5
Max:	1.81E+4	1.98E+6
Min:	3.41E+3	4.91E+4

45% RH

Item	ρYellow side, GΩ-cm)	ρWhite side, GΩ-cm)
Average:	7.32E+3	3.23E+3
Max:	1.81E+4	1.27E+4
Min:	3.41E+3	7.44E+2

As measured from both sides and at both humidity points, the fabric is **insulative**.

b. Trellchem HPS Type TE

12% RH

Item	ρ(Red side, GΩ-cm)	ρ(White side, GΩ-cm)
Average:	9.54E+4	7.43E+4
Max:	4.74E+5	2.04E+5
Min:	2.02E+4	8.28E+3

45% RH

Item	ρ(Red side, GΩ-cm)	ρ(White side, GΩ-cm)
Average:	4.48E+3	5.26E+2
Max:	1.18E+4	1.15E+3
Min:	3.15E+2	1.75E+2

As measured from both sides and at both humidity points, the fabric is **insulative**.

c. Reeves SCAPE Suit Fabric

12% RH

Item	ρTan side, TΩ-cm)	ρGray side, TΩ-cm)
Average:	1.89E+2	1.44E+3
Max:	3.37E+2	5.53E+3
Min:	2.40E+1	2.33E+2

45% RH

Item	ρ(Tan side, TΩ-cm)	ρ(Gray side, TΩ-cm)
Average:	2.80	2.77
Max:	4.05	3.20
Min:	2.02	2.22

As measured from both sides and at both humidity points, the fabric is **insulative**.

d. Respirex SCAPE Suit Fabric

12% RH

Item	ρ(Tan side, TΩ-cm)	ρ(Gray side, TΩ-cm)
Average:	1.97	2.62
Max:	4.47	3.90
Min:	1.18	1.14

45% RH

Item	ρ(Tan side, TΩ-cm)	ρ(Gray side, TΩ-cm)
Average:	8.47E+4	7.12E+4
Max:	1.49E+5	1.43E+5
Min:	3.24E+4	5.44E+4

As measured from both sides, the fabric is **insulative** at 12% relative humidity.

e. Saint Gobain Fabric

2.4% RH

Item	ρ(GΩ-cm)
Average:	242.3
Max:	388
Min:	133

51% RH

Item	ρ(GΩ-cm)
Average:	191.1
Max:	248
Min:	154

As measured at both humidity points, the fabric is **insulative**.

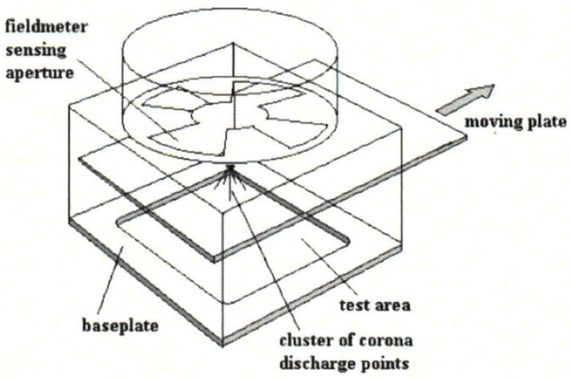
1.4 Summary of Surface and Volume Resistivity Results

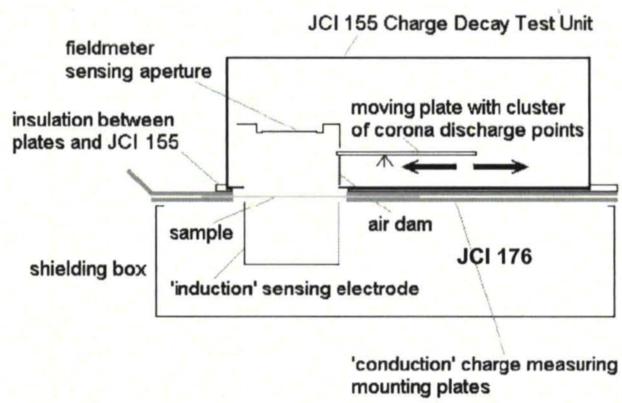
	Resistance Testing with PRS-801		
Material	**Surface Resistivity (Ω)**	**Statically Dissipative? Insulative? Conductive?**	**Volume Resisitivity (Ω*cm)**
Reeves Gray Side (room humidity)	3.73E+12	Insulative	3.82E+14
Reeves Gray Side (low humidity)	1.68E+13	Insulative	1.44E+15
Reeves White Side (room humidity)	3.85E+12	Insulative	3.86E+14
Reeves White Side (low humidity)	1.09E+13	Insulative	1.89E+14
Trellchem HPS Red Side (room humidity)	5.58E+11	Insulative	6.06E+14
Trellchem HPS Red Side (low humidity)	5.30E+12	Insulative	9.54E+13
Trellchem HPS White Side (room humidity)	2.63E+12	Insulative	7.12E+13
Trellchem HPS White Side (low humidity)	1.34E+12	Insulative	7.43E+13
Trellchem VPS Yellow Side (room humidity)	2.42E+11	Insulative	1.66E+13
Trellchem VPS Yellow Side (low humidity)	1.80E+11	Insulative	7.32E+12
Trellchem VPS White Side (room humidity)	6.75E+11	Insulative	4.37E+14
Trellchem VPS White Side (low humidity)	4.19E+12	Insulative	4.15E+14
Respirex White Side (room humidity)	9.62E+12	Insulative	9.81E+13
Respirex White Side (low humidity)	1.97E+12	Insulative	1.23E+14
Respirex Gray Side (room humidity)	1.07E+12	Insulative	1.56E+14
Respirex Gray Side (low humidity)	2.62E+12	Insulative	2.10E+14
SCAPE Suit Boot- main part (room humidity)	2.74E+09	Statically Dissipative	-
SCAPE Suit Boot- top band (room humidity)	7.00E+11	Insulative	-
SCAPE Suit Glove- main part (room humidity)	2.13E+07	Statically Dissipative	-
SCAPE Suit Glove- band (room humidity)	4.73E+12	Insulative	-
Saint Gobain (room humidity)	3.66E+11	Insulative	1.91E+11
Saint Gobain (low humidity)	1.82E+12	Insulative	2.42E+11

According to ANSI ESD standards STM11.11 and STM11.12, all of the SCAPE materials are insulating and should not be capable of dissipating electrostatic charge to ground. Only the main part of the boot and glove are statically dissipative at room humidity.

2.0 Corona Charge Decay

Charge Decay tests are performed on candidate materials to test their ability to dissipate charge. Corona charge deposition is chosen because surface charge levels can be deposited in a controlled manner. Tests are performed using a JCI 155v5 Charge Decay Test Unit conforming to British Standard 7506 "Methods for Measurements in electrostatics"*. This device deposits a consistent amount of positive or negative charge onto the surface of a material by ionizing the air molecules with high voltage corona needle points up to ±10,000 volts. The JCI 155v5 sits on top of a JCI 176 Charge Measurement Sample Support system which has the ability to measure the total amount of charge transferred to the sample. The total amount of charge transferred to the sample consists of both the charge that "leaves" the surface of the sample and the charge that remains. The samples are mounted between two conducting plates. Once the charge is deposited onto the surface of the test material, the plate containing the corona points is retracted (within 20 ms) and a field meter is exposed. This field meter measures and records the surface voltage on the material as a function of time. The time it takes for the surface voltage to reach 1/e (1/2.71828) or 37% of its maximum value is called the *decay time* or τ. For materials to posses "good" ESD behavior, they should dissipate the charge faster than one could deposit it in the field. Decay times should be less than one second to "pass" ESD criteria otherwise materials "fail" ESD.





There are at least three runs performed per side of each sample. Tests are performed at high (~55%) and low (~20%) relative humidity. In addition to the charge decay times recorded, the maximum average surface potential measured using both positive and negative polarities and capacitance loading values are also recorded.

*British Standard BS 7506, Methods for Measurements in Electrostatics, Part 2 (1995).

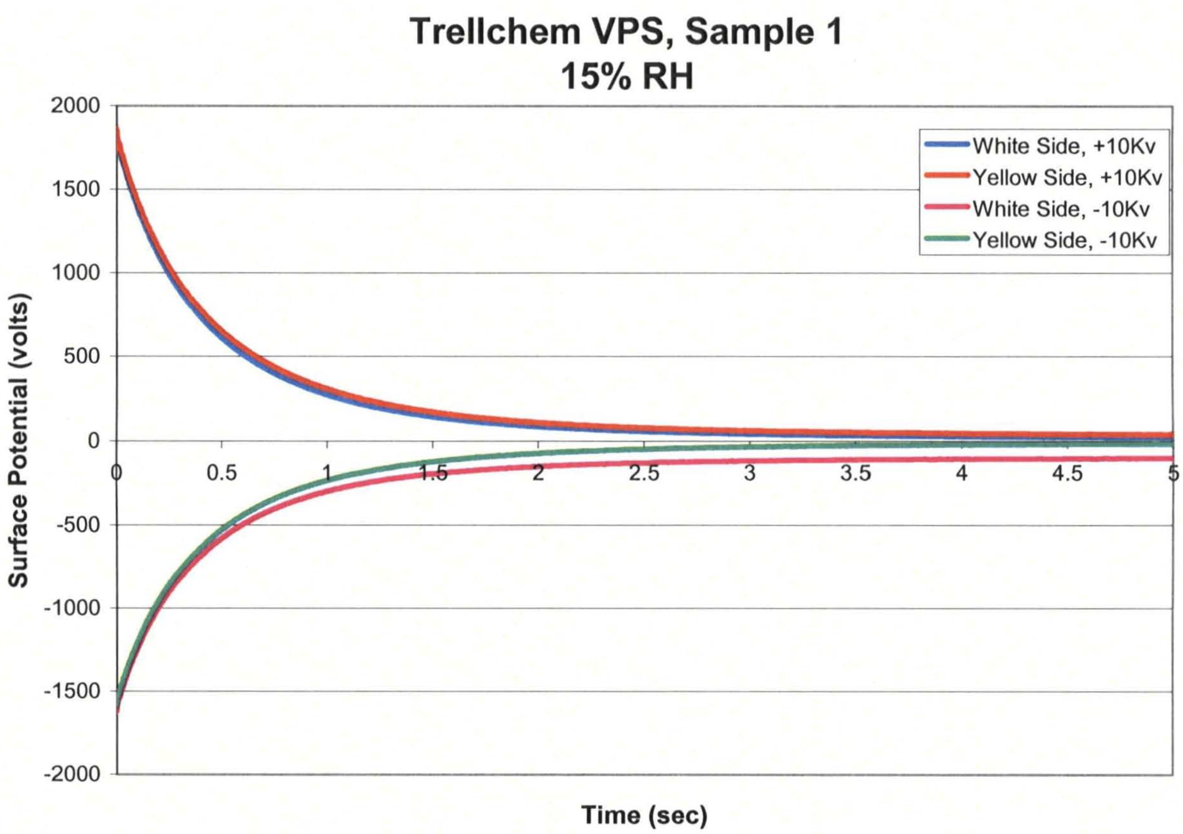
2.1 Corona Charge Decay Results

a. **Trellchem VPS Type TE**

Low Humidity ~15% RH

Side	Ave. CL	Time to discharge to 1/e (s)	Ave Vpk when charged with -10Kv (v)	Ave Vpk when charged with +10Kv (v)
White	1.26	0.4355	-1621.46	1843.15
Yellow	1.296	0.4401	-1563.77	1817.98

An example of the charge decay curves for the VPS fabrics are given in the figure below.

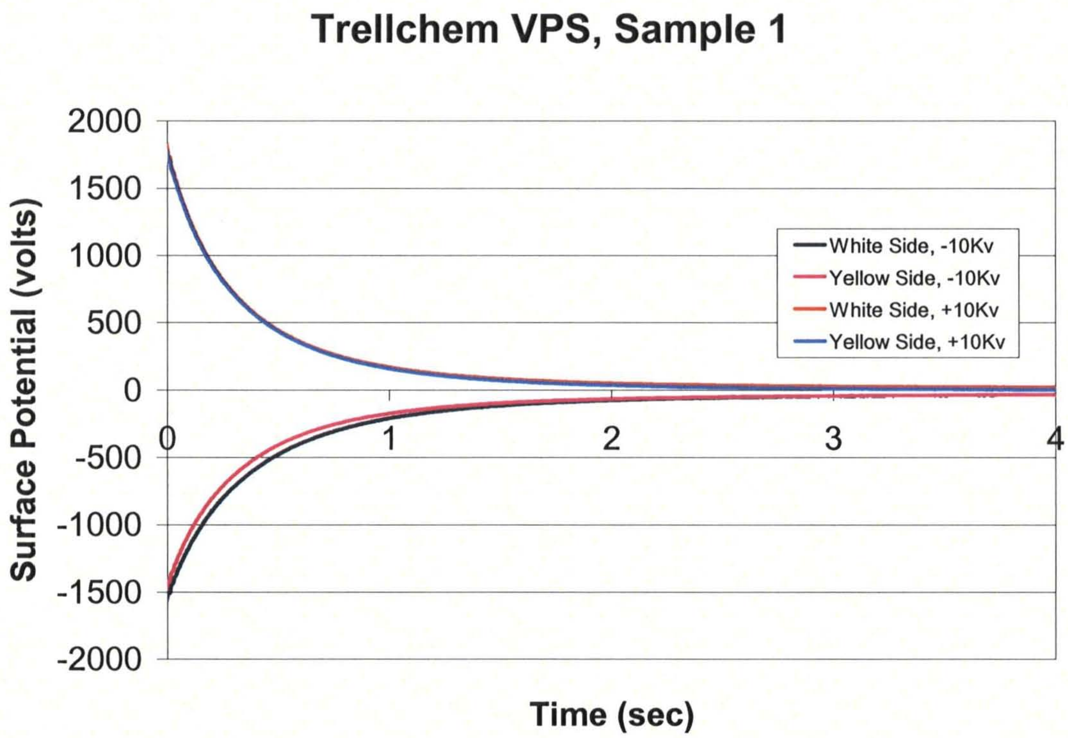


Trellchem VPS Corona Charge Decay Curves for ~ 15% RH

Room Humidity~45% RH

Side	Ave. CL	Time to discharge to 1/e (s)	Ave Vpk when charged with -10Kv (v)	Ave Vpk when charged with +10Kv (v)
White	1.3822	0.35089	-1491.41	1816.34
Yellow	1.38297	0.34551	-1449.07	1778.77

An example of the charge decay curves for the VPS fabrics are given in the figure below.



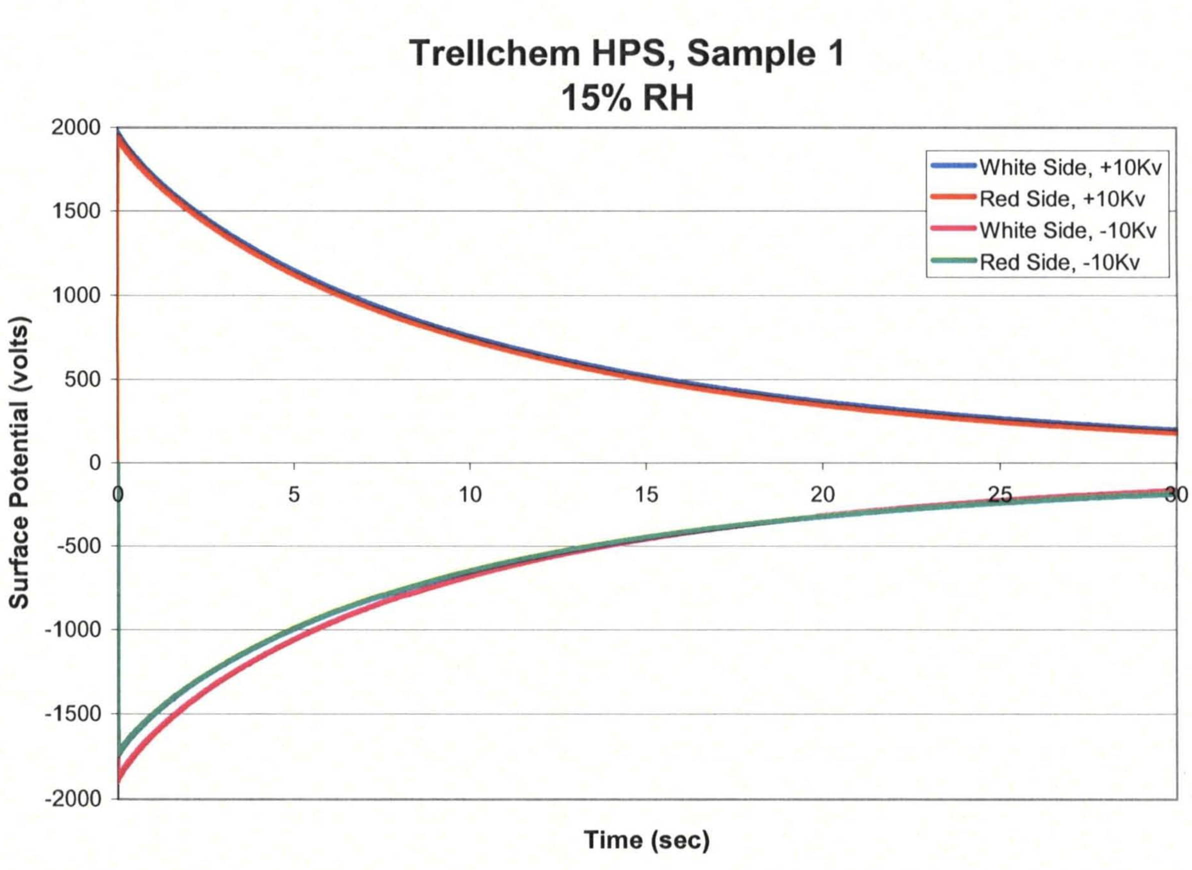
Trellchem VPS Corona Charge Decay Curves for ~ 45% RH

b. Trellchem HPS Type TE

Low Humidity ~15% RH

Side	Ave. CL	Time to discharge to 1/e (s)	Ave Vpk when charged with -10Kv (v)	Ave Vpk when charged with +10Kv (v)
White	1.08	10.2	-1897	1989
Red	1.14	10.17	-171.01	1967.04

An example of the charge decay curves for the HPS fabrics are given in the figure below.

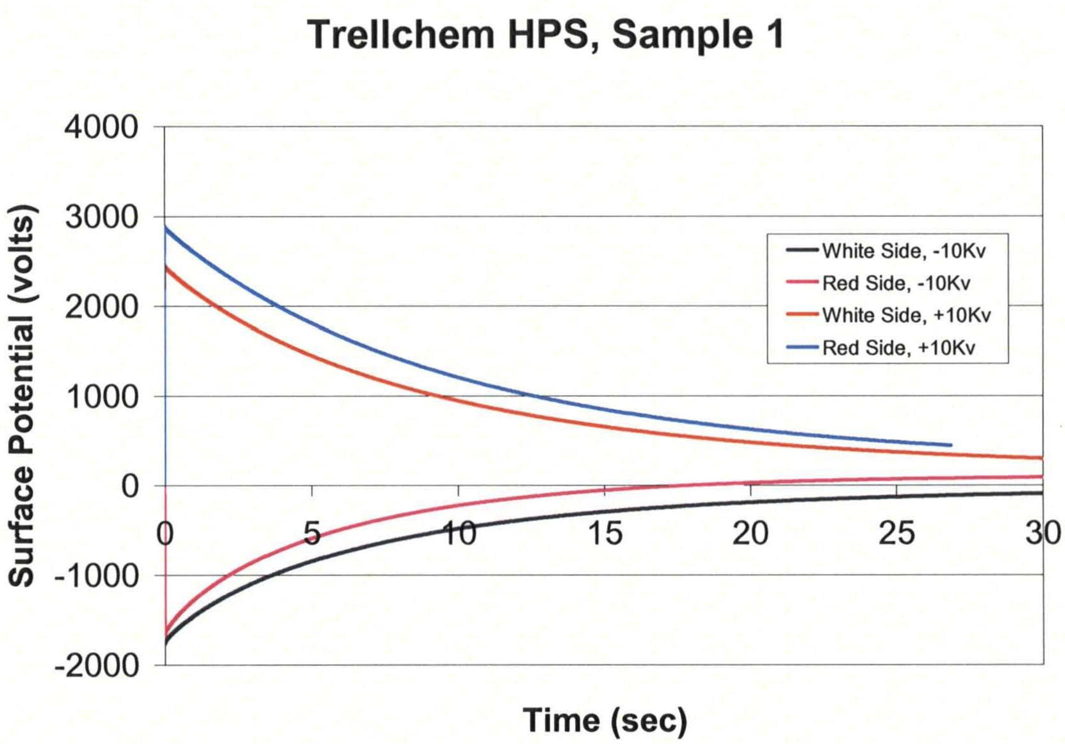


Trellchem HPS Corona Charge Decay Curves for ~ 15% RH

Room Humidity~45% RH

Side	Ave. CL	Time to discharge to 1/e (s)	Ave Vpk when charged with -10Kv (v)	Ave Vpk when charged with +10Kv (v)
White	0.9587	7.95537	-1795.18	2078.58
Red	1.04097	7.95684	-1737.57	2068.69

An example of the charge decay curves for the VPS fabrics are given in the figure below.



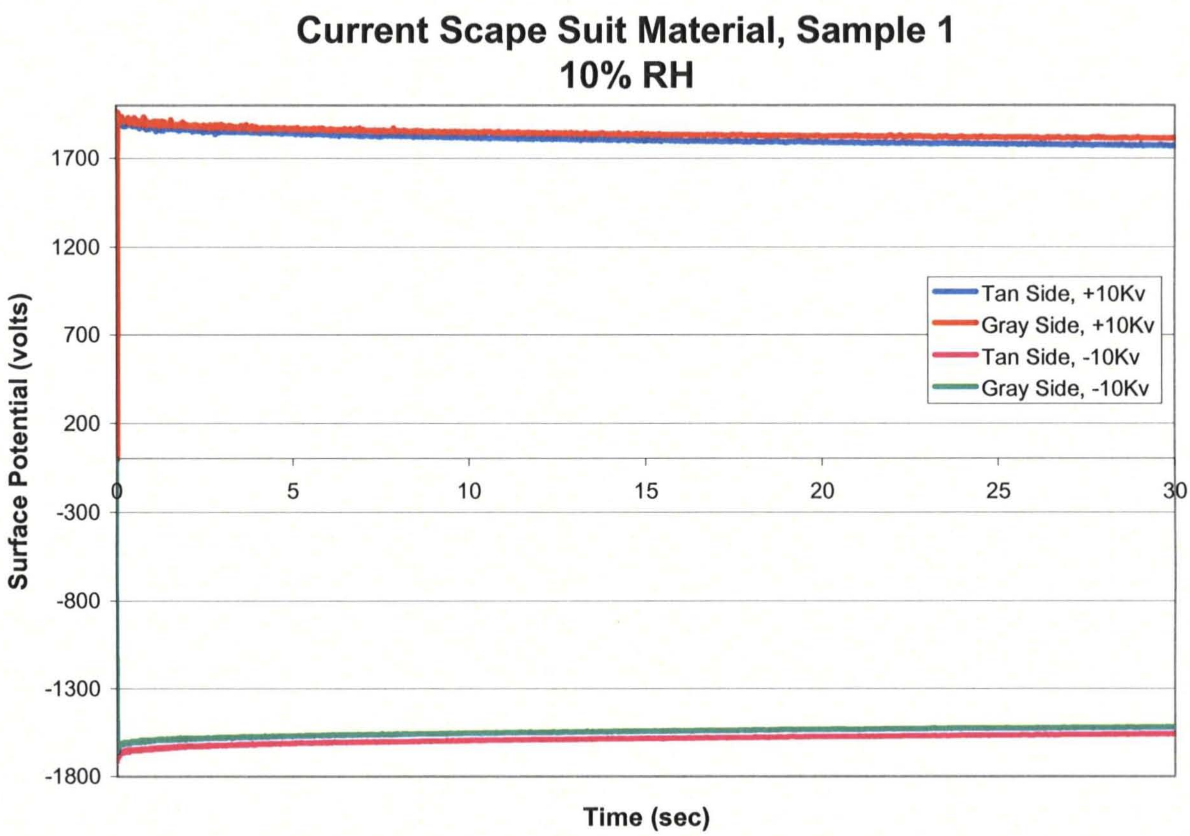
Trellchem HPS Corona Charge Decay curves for ~ 45% RH

c. Reeves SCAPE Suit Fabric

Low Humidity ~10% RH

Side	Ave. CL	Ave. Vpk When Charged with -10Kv (v)	Ave. Vpk When Charged with +10Kv (v)	Decay?
Tan	1.09	-1663.41	1941.16	Slow Decay
Gray	1.07	-1619.98	1898.38	Slow Decay

The tests were terminated at 60 seconds with little decay noted. No 1/e voltage values found. A sample of this data is graphed in the figure below.

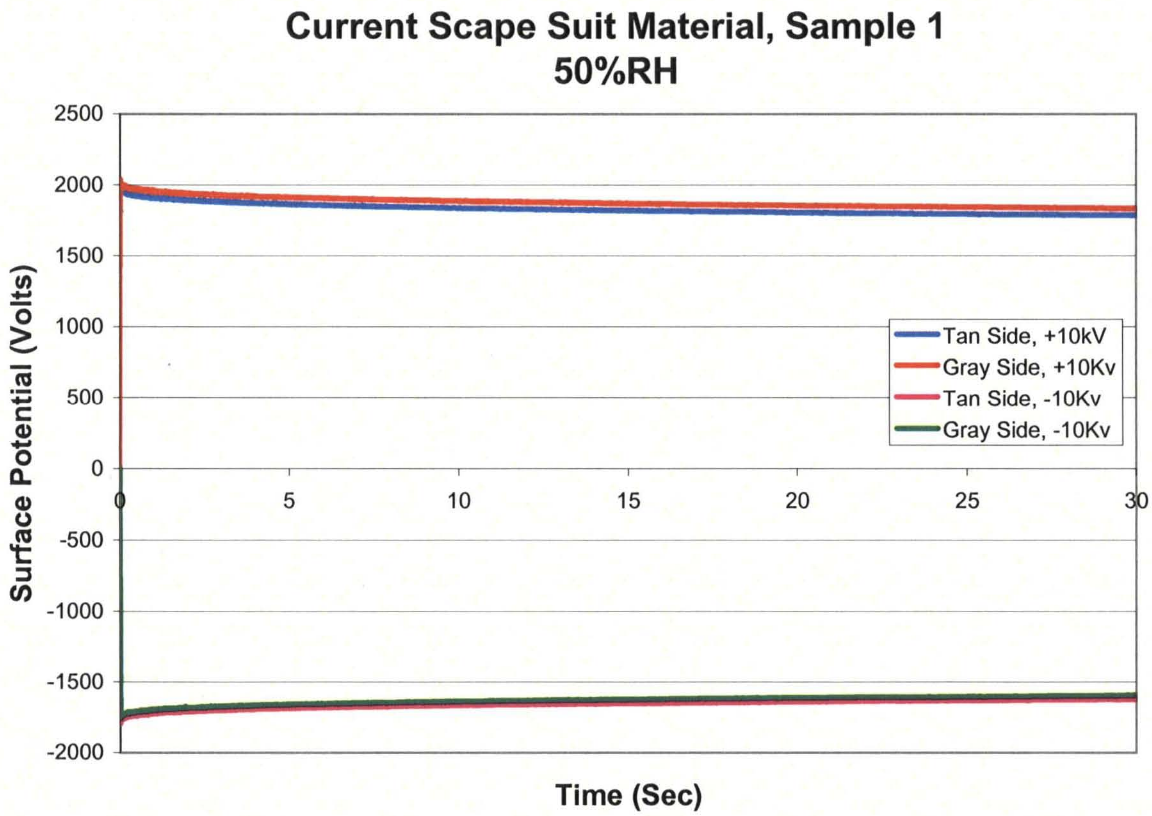


Reeves SCAPE Suit Fabric Corona Charge Decay Curves for 10% RH

Room Humidity~50% RH

Side	Ave. CL	Ave Vpk when Charged with -10Kv (v)	Ave Vpk when Charged with +10Kv (v)	Decay ?
Tan	1.088	-1778.80	1966.99	Slow Decay
Gray	1.042	-1758.87	1991.19	Slow Decay

The tests were terminated at 60 seconds with little decay noted. No 1/e voltage values found. A sample of this data is graphed in the figure below.

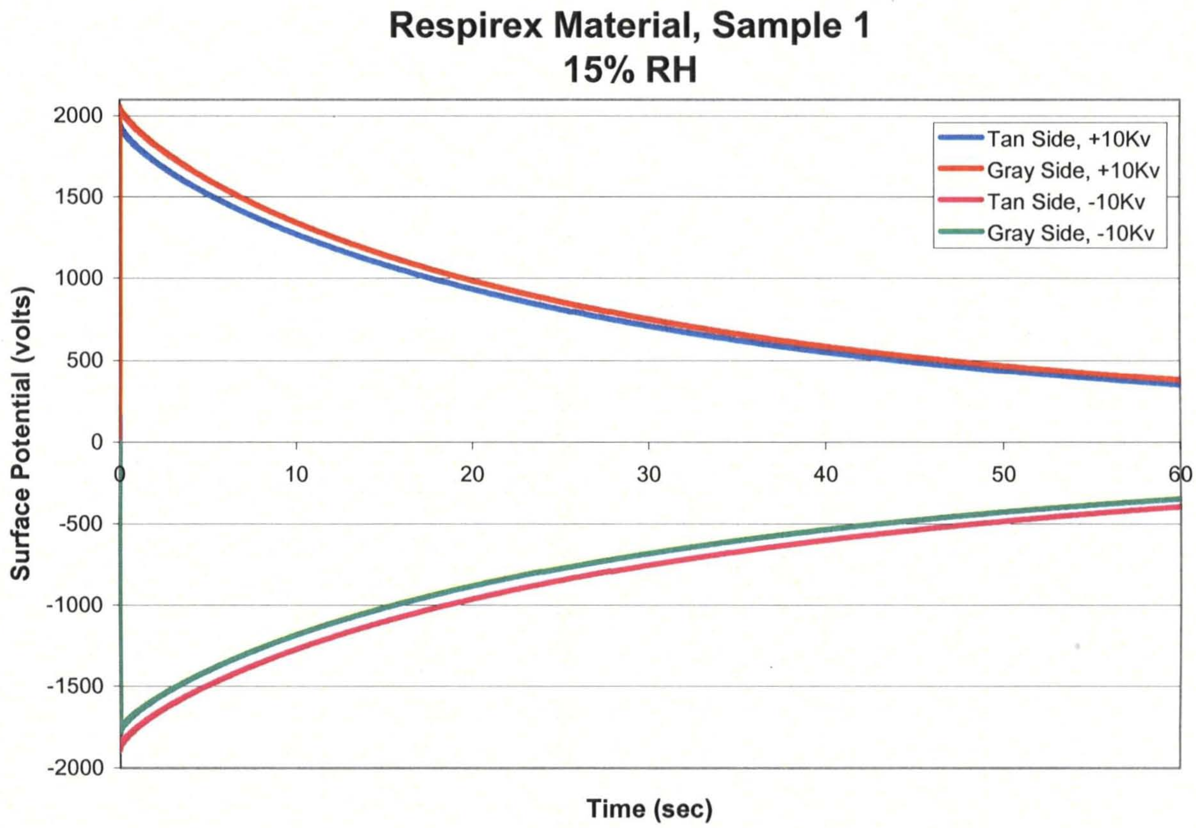


Reeves SCAPE Suit Fabric Corona Charge Decay Curves for 50% RH

d. Respirex

Low Humidity~15% RH

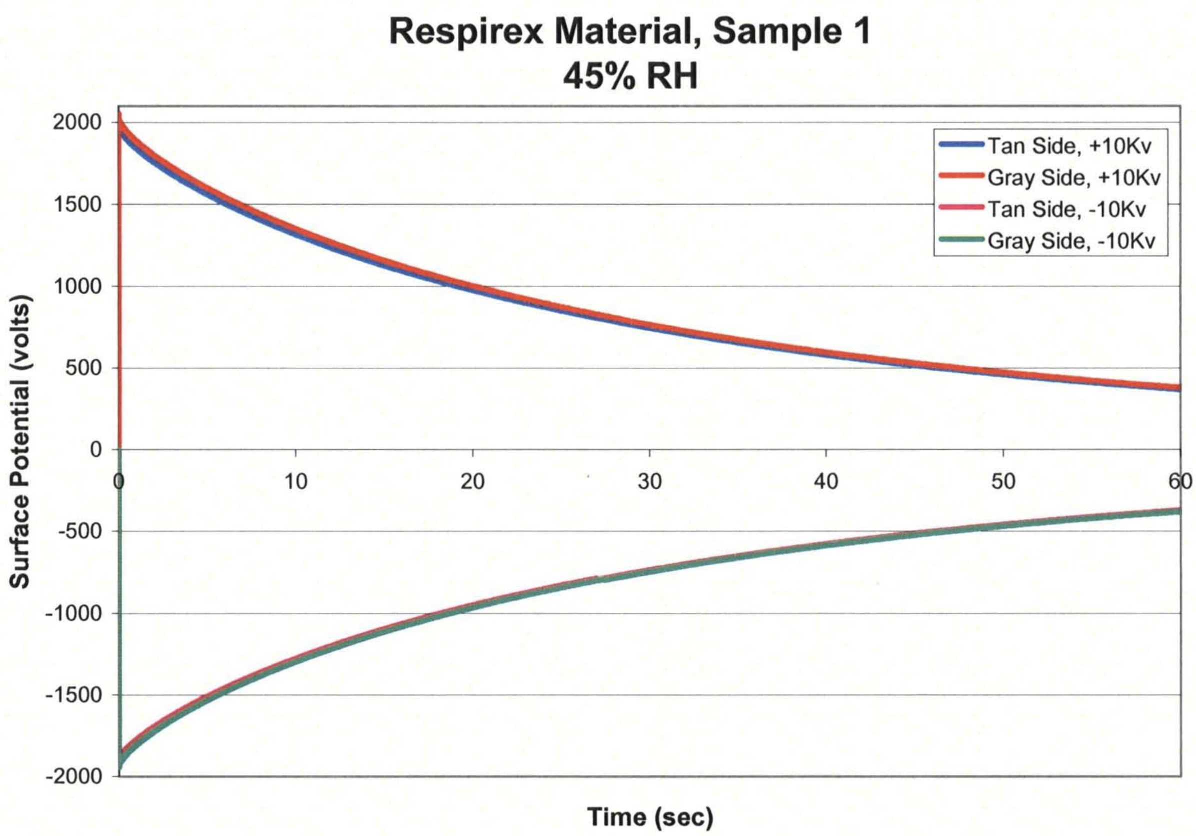
Side	Ave. CL	Ave Vpk when Charged with -10Kv (v)	Ave Vpk when Charged with +10Kv (v)	Time to 1/e (sec)
Tan	1.126	-1854.33	1982.75	33.29
Gray	1.046	-1785.5	2029.133	31.72



Respirex SCAPE Suit Fabric Corona Charge Decay Curves for 15% RH

Room Humidity~50% RH

Side	Ave. CL	Ave Vpk when Charged with -10Kv (v)	Ave Vpk when Charged with +10Kv (v)	Time to 1/e (sec)
Tan	1.092	-1937.04	2031.54	32.109
Gray	1.028	-1946.44	2053.98	31.56



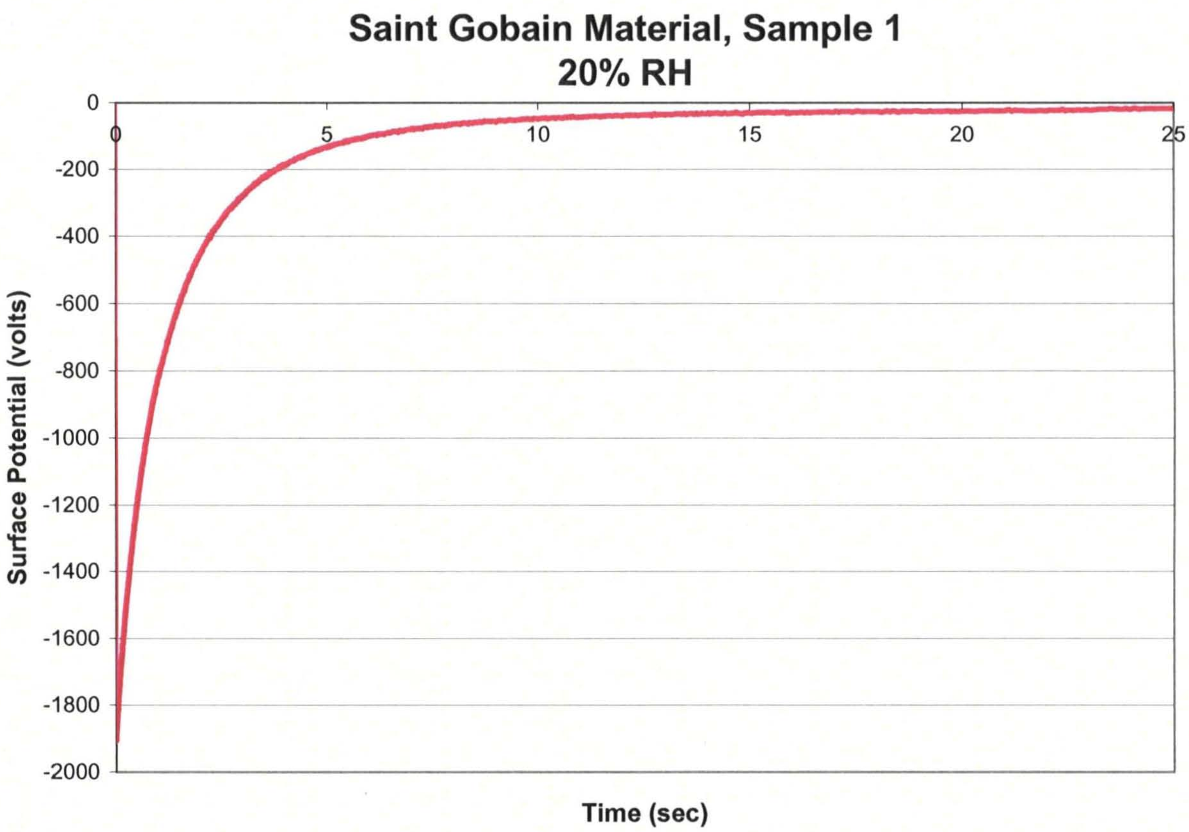
Respirex SCAPE Suit Fabric Corona Charge Decay Curves for 45% RH

e. <u>Saint Gobain</u>

Tests performed on the Saint Gobain materials were conducted on one side only since the materials are homogeneous. Only one charge polarity was chosen to perform charge decay tests.

Low Humidity~20% RH

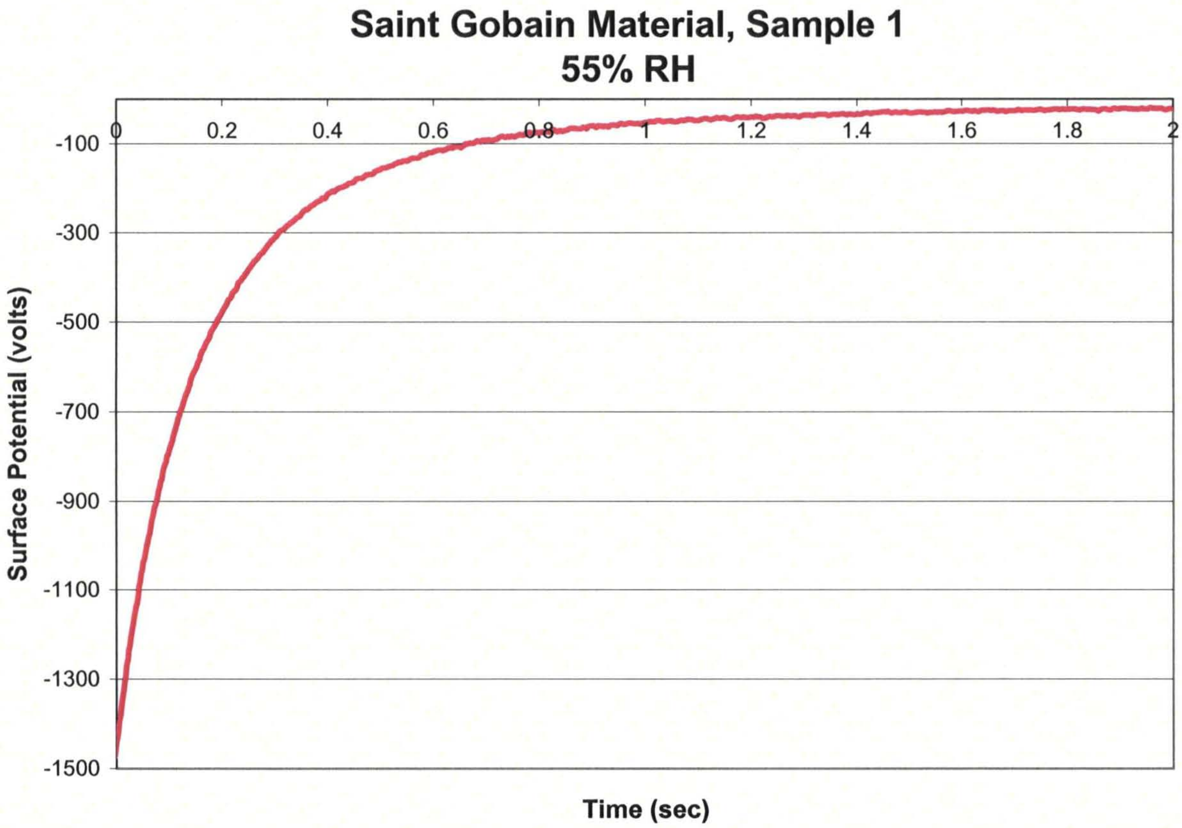
Ave. CL	Ave. Vpk when Charged with -10Kv (v)	Time to 1/e (sec)
.977	-1840	1.09



Saint Gobain SCAPE Suit Fabric Corona Charge Decay Curves for 20% RH

Room Humidity~55% RH

Ave. CL	Ave Vpk when Charged with -10Kv (v)	Time to 1/e (sec)
1.74	-1490	0.167



Saint Gobain SCAPE Suit Fabric Corona Charge Decay Curves for 55% RH

2.2 Summary of Corona Charge Decay Results

Material	Time to 1/e (sec)	Max. Surface Potential with -10 kV (volts)	Max. Surface Potential with +10 kV (volts)	CL	Pass/ Fail
Reeves Gray Side (room humidity)	Not Reached	-1758.87	1991.19	1.04	Fail
Reeves Gray Side (low humidity)	Not Reached	-1619.98	1898.38	1.07	Fail
Reeves White Side (room humidity)	Not Reached	-1778.8	1966.99	1.09	Fail
Reeves White Side (low humidity)	Not Reached	-1663.41	1941.16	1.09	Fail
Trellchem HPS Red Side (room humidity)	7.96	-1737.57	2068.69	1.04	Fail
Trellchem HPS Red Side (low humidity)	10.2	-1741.01	1967.04	1.14	Fail
Trellchem HPS White Side (room humidity)	7.96	-1795.18	2078.58	0.96	Fail
Trellchem HPS White Side (low humidity)	10.2	-1897.46	1989.54	1.08	Fail
Trellchem VPS Yellow Side (room humidity	0.346	-1449.07	1778.77	1.38	Pass
Trellchem VPS Yellow Side (low humidity)	0.440	-1563.77	1817.98	1.30	Pass
Trellchem VPS White Side (room humidity)	0.351	-1491.41	1816.34	1.38	Pass
Trellchem VPS White Side (low humidity)	0.436	-1621.46	1843.15	1.26	Pass
Respirex White Side (room humidity)	32.1	-1937.04	2031.54	1.09	Fail
Respirex White Side (low humidity)	33.3	-1854.33	1982.75	1.13	Fail
Respirex Gray Side (room humidity)	31.6	-1946.44	2053.98	1.03	Fail
Respirex Gray Side (low humidity)	31.7	-1785.5	2029.13	1.05	Fail
Saint Gobain (room humidity)	0.167	-1490	-	1.74	Pass
Saint Gobain (low humidity)	1.09	-1840	-	0.98	Fail

The charge decay results are quite surprising. According to the surface resistivity and volume resistivity results, charge placed on the surface of the materials should not dissipate to ground. However, charge placed on both types of Trellchem, the Saint Gobain materials and the Respirex materials *did* dissipate to ground unlike the Reeves materials which held the static charge. Additionally, the Trellchem VPS and the Saint Gobain at high humidity dissipated electrostatic charge very quickly below one second consistent with a statically dissipative or conductive material. Charge dissipation times and the maximum charge deposition was not heavily dependent on the side of the material charged or the ambient humidity conditions present during charge decay testing for the Trellchem and Respirex materials.

"CL" denotes capacitance loading which is a measure of how well the materials concentrate the electric field lines within themselves. For example, large values of CL = 40 means that the electric field above the surface is reduced by a factor of 40 as a result of field confinement within the material. Therefore, if a grounded object approaches the charged surface the electric field will stay within the material and not the object making it less likely to cause a spark in air. Here however nearly all of the electric field lines extend out in space and are not confined to the material given by values close to one for all of the materials tested.

Although the Reeves material did not dissipate charge on its own, the application of Staticide to the surface, the Reeves material did dissipate charge as shown in the next section.

2.3 Investigation of the use of Dawn and Isopropyl Alcohol as Additives to Staticide

Material: Reeves
Equipment used: JCI 155v5 with JCI 176 base
Humidity: 55% relative humidity

Summary of Staticide and Dawn Mixture Data from Decay Tests

	Immediately after application		**24 Hours after application**	
Mixture applied	Vpk (volts)	Decay time to 1/e (sec)	Vpk (volts)	t pk to 1/e (sec)
None	-2097.56	Slow Decay	-2097.56	Slow Decay
100:0 (full staticide)	-1600.22	0.207031	-2144.51	5.75684
100:1 (staticide : dawn)	-2047.97	Slow Decay	-2127.42	Slow Decay
100:2 (staticide : dawn)	-1769.56	0.429688	-2027.88	1.2959
100:3 (staticide : dawn)	-1298.51	0.154297	-2049.88	1.33496
100:4 (staticide : dawn)	-1438.09	0.185547	-1895.48	0.404297
100:5 (staticide : dawn)	-1146.46	0.0917969	-1846.19	0.349609

Summary of Staticide and Isopropyl Alcohol Mixture Data from Decay Tests

	Immediately after application		**4 Hours after application**	
Mixture applied	Vpk (volts)	Decay time to 1/e (sec)	Vpk (volts)	t pk to 1/e (sec)
None	-2097.56	Slow Decay	-2097.56	Slow Decay
100:0 (full staticide)	-1600.22	0.207031	-1939.6	0.542969
100:1 (staticide : IPA)	-1223.73	0.109375	-1965.21	0.5
100:2 (staticide : IPA)	-1541.46	0.138672	-1775.59	0.300781
100:3 (staticide : IPA)	-1921.61	0.570313	-2118.19	4.99121
100:4 (staticide : IPA)	-1685.82	0.193359	-2084.79	2.60645
100:5 (staticide : IPA)	-1930.71	0.693359	-2130	13.4385

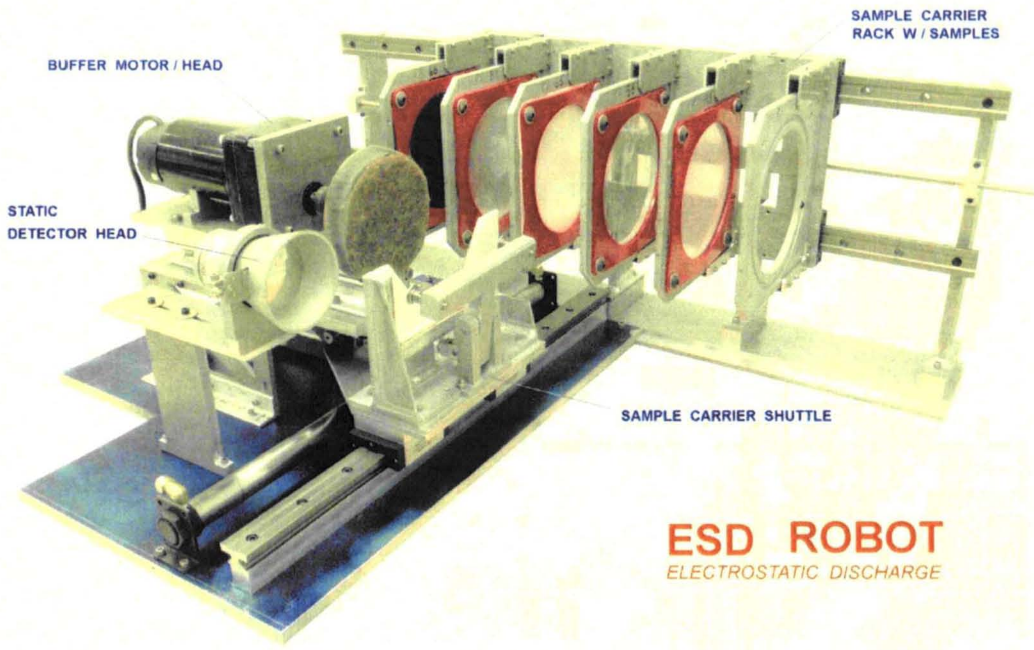
Recommendations based on Charge decay tests:

- The use of full Staticide (no additive used, applied same day as use) is sufficient to bring the charge decay properties into acceptable limits (decay time to 1/e is under 1 sec).
- If the suit is to be used the next day after application of the Staticide, use a mixture of 5 parts Dawn to every 100 parts Staticide. This mixture has significantly better charge decay properties then full Staticide applied 24 hours ahead of time.
- The use of Isopropyl Alcohol as an additive to Staticide has no significant positive affect on the properties of Staticide, because of this it should not be used for this application.

3.0 Triboelectric Charge Decay

An alternate method to charge a material is by contact and frictional electrification or triboelectric charging. The ESPL has been performing triboelectric charging tests of materials for over forty years. The Kennedy Space Center uses Standard Test Method MMA-1985-79 entitled "Standard Test Method for Evaluating Triboelectric Charge Generation and Decay"*. This method of evaluating the electrostatic properties of materials records the charge decay after the test material is rubbed with either wool or PTFE felt. A device called the ESD Robot used to test materials is shown below.

Two seven-inch square test samples are cut out of each of the stock materials to be tested. They are mounted onto an aluminum frame and acclimated at 75°F for 24 hours prior to testing under relative humidities of 45% and 30%. The aluminum frames are then mounted on the sample carrier shuttle that operates in two positions. The first position allows a PTFE felt disk or wool disk (five inches in diameter) to rub against the test sample using five pounds of force. The disk rotates at 400 revolutions per minute for ten seconds to "saturate" the sample with charge. After ten seconds the sample moves into the second position in front of a static detector head that records the surface potential while the aluminum frame is grounded. Shown below is the Keithley model 2501 Static Detector head. However, here we used JCI model 140 Static Monitor with a guard to record surface potential. The current KSC standard dictates that materials "pass" the ESD test criteria if the surface voltage is below 350 volts after five seconds, otherwise the materials "fail'.

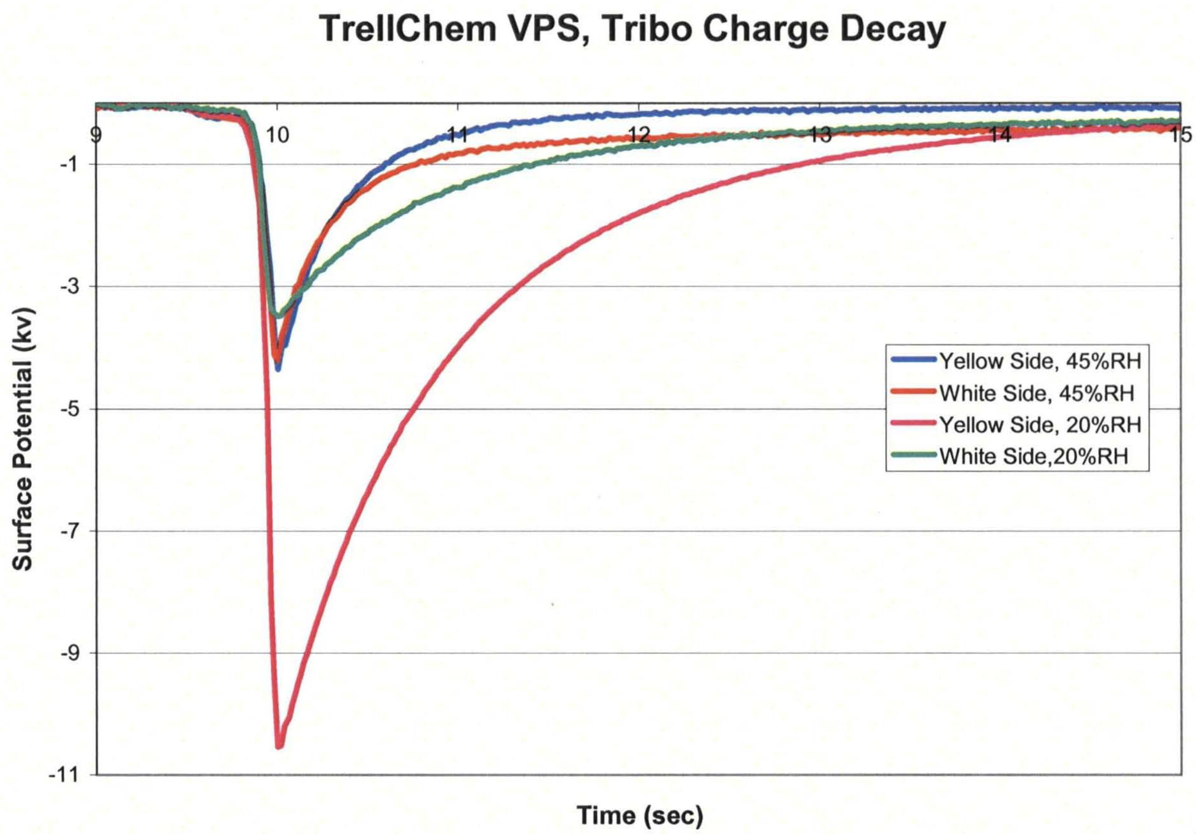


*Finchum, A., "Standard Test Method for Evaluating Triboelectric Charge Generation and Decay", KSC Test Standard MMA-1985-98, Revision 3 (1998).

3.1 Triboelectric Charging Results

a. **Trellchem VPS Type TE**

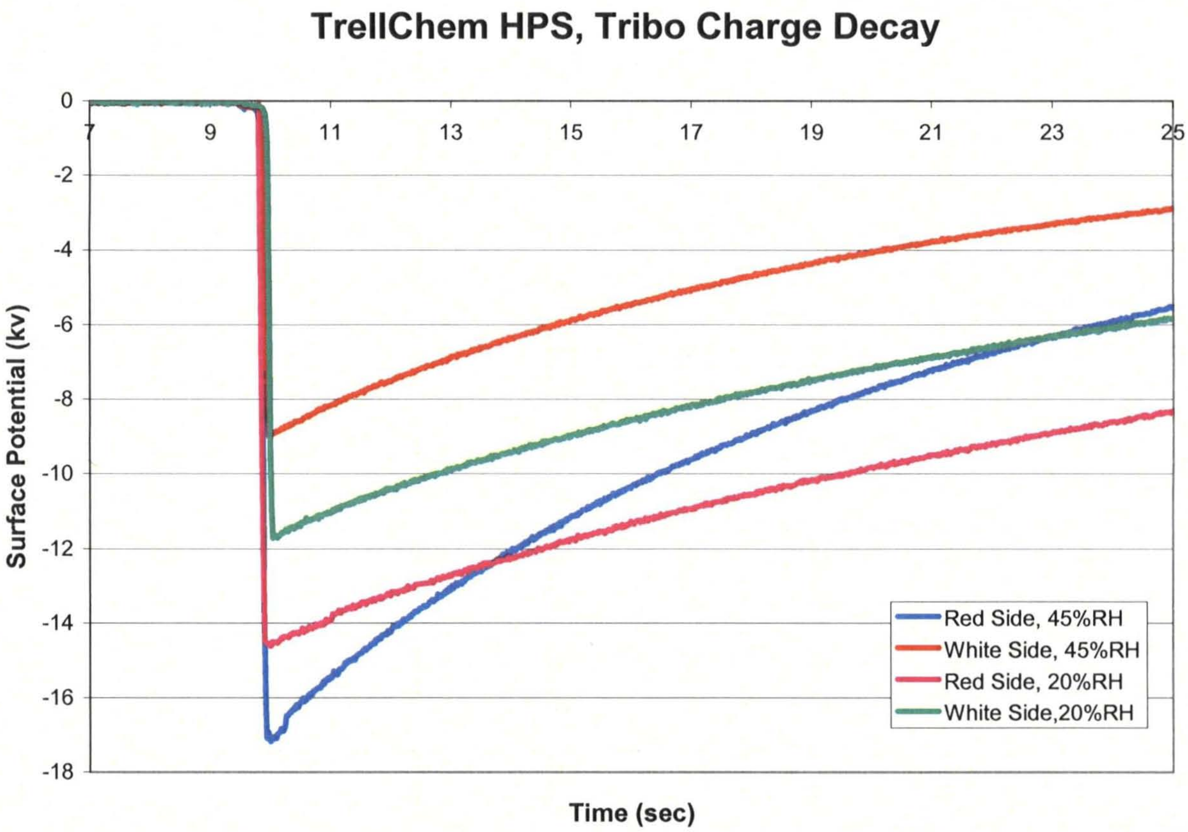
	Room Humidity ~ 45% RH		Low Humidity ~ 20%RH	
Side	**Decay time to 1/e (s)**	**Vpk (kV)**	**Decay time to 1/e (s)**	**Vpk (kV)**
White	0.454	-4.46	1.04	-3.42
Yellow	0.392	-4.45	1.03	-12.34



Trellchem VPS Tribo Charge Decay Curves

b. Trellchem HPS Type TE

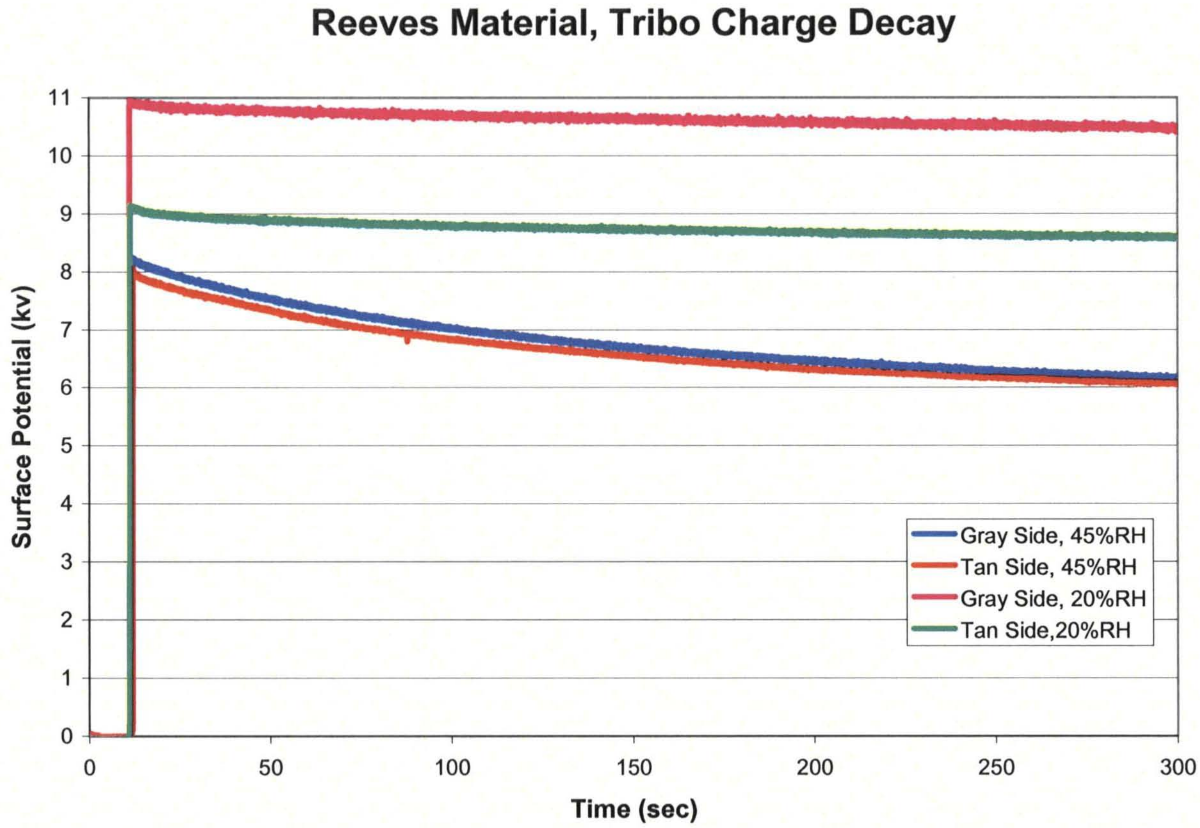
	Room Humidity ~ 45% RH		Low Humidity ~ 20%RH	
Side	Decay time to 1/e (s)	Vpk (kV)	Decay time to 1/e (s)	Vpk (kV)
White	12.88	-9.42	23.13	-11.51
Red	12.17	-17.32	27.33	-15.83



Trellchem HPS Tribo Charge Decay Curves

c. Reeves SCAPE Suit Fabric

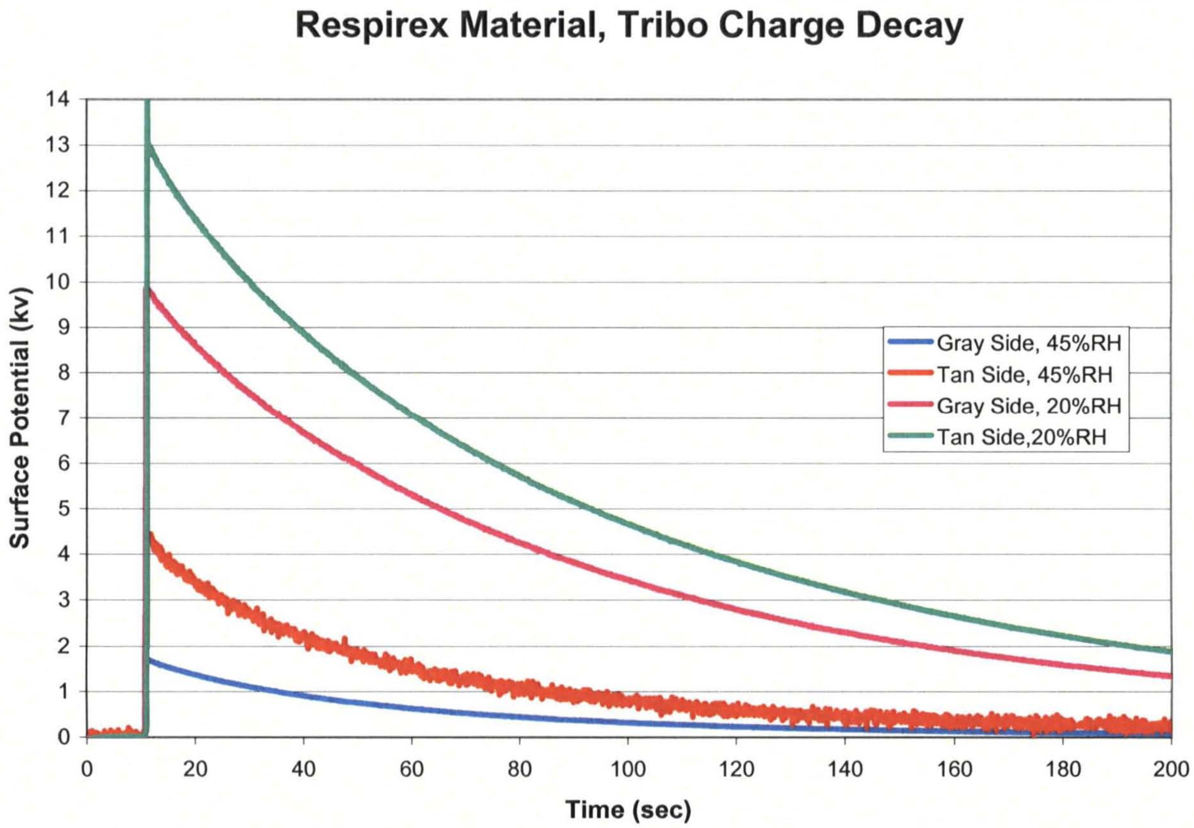
	Room Humidity ~ 45% RH		Low Humidity ~ 20%RH	
Side	**Decay time to 1/e (s)**	**Vpk (kV)**	**Decay time to 1/e (s)**	**Vpk (kV)**
Tan	Not Reached	9.16	Not Reached	10.5
Gray	Not Reached	8.98	Not Reached	12.47



Reeves Tribo Charge Decay Curves

d. Respirex

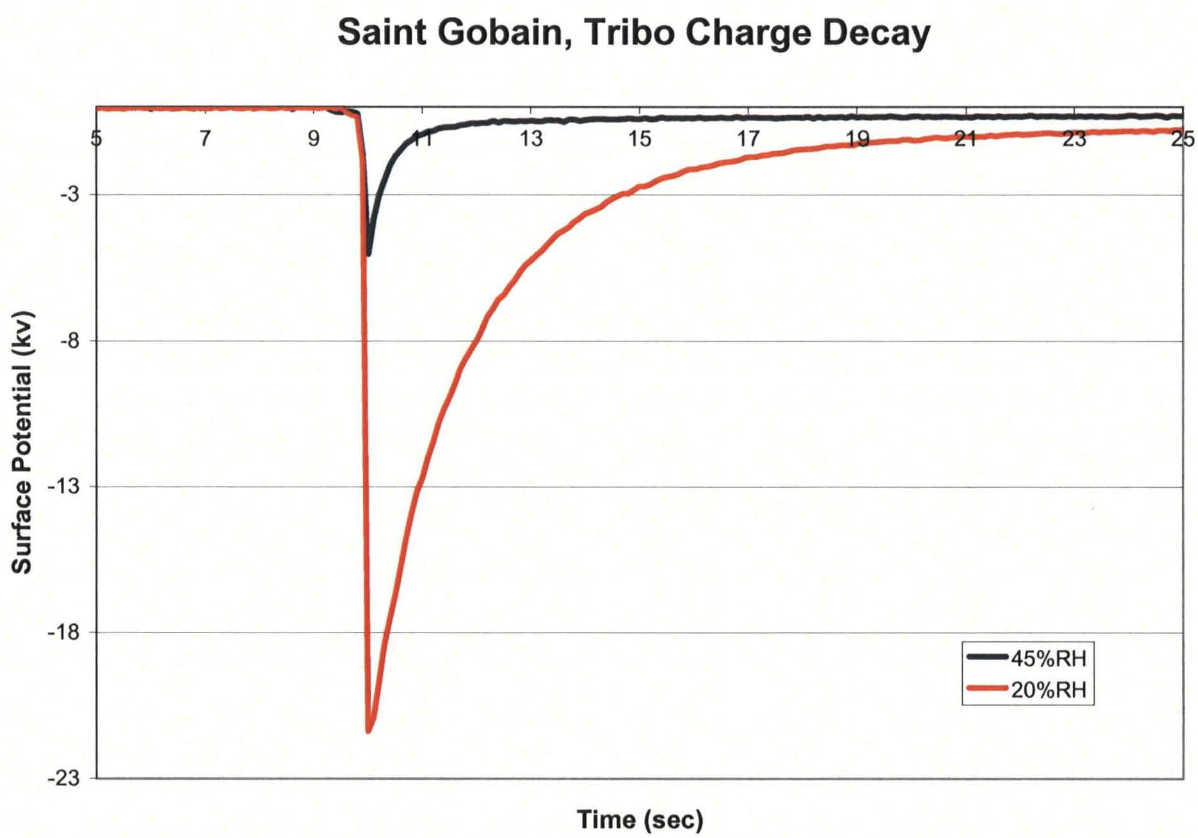
	Room Humidity ~ 45% RH		Low Humidity ~ 20%RH	
Side	Decay time to 1/e (s)	Vpk (kV)	Decay time to 1/e (s)	Vpk (kV)
Tan	44.99	4.11	77.98	12.17
Gray	35.19	2.13	77.7	7.9



Respirex Tribo Charge Decay Curves

e. Saint Gobain

Room Humidity ~ 45% RH		Low Humidity ~ 20%RH	
Decay time to 1/e (s)	**Vpk (kV)**	**Decay time to 1/e (s)**	**Vpk (kV)**
.40	-6.69	1.93	-21.4



Saint Gobain Tribo Charge Decay Curves

3.2 Summary of Triboelectric Charge Decay Results

Material	Time to 1/e (sec)	Max. Surface Potential (kV)	Pass/Fail
Reeves Gray Side (room humidity)	Not Reached	8.98	Fail
Reeves Gray Side (low humidity)	Not Reached	12.47	Fail
Reeves White Side (room humidity)	Not Reached	9.16	Fail
Reeves White Side (low humidity)	Not Reached	10.5	Fail
Trellchem HPS Red Side (room humidity)	12.17	-17.32	Fail
Trellchem HPS Red Side (low humidity)	27.33	-15.83	Fail
Trellchem HPS White Side (room humidity)	12.88	-9.42	Fail
Trellchem HPS White Side (low humidity)	23.13	-11.51	Fail
Trellchem VPS Yellow Side (room humidity)	0.392	-4.45	Pass
Trellchem VPS Yellow Side (low humidity)	1.03	-12.34	Pass
Trellchem VPS White Side (room humidity)	0.454	-4.46	Fail
Trellchem VPS White Side (low humidity)	1.04	-3.42	Pass
Respirex White Side (room humidity)	44.99	4.11	Fail
Respirex White Side (low humidity)	77.98	12.17	Fail
Respirex Gray Side (room humidity)	35.19	2.13	Fail
Respirex Gray Side (low humidity)	77.7	7.9	Fail
Saint Gobain (room humidity)	.40	-6.69	Fail
Saint Gobain (low humidity)	1.93	-21.4	Fail

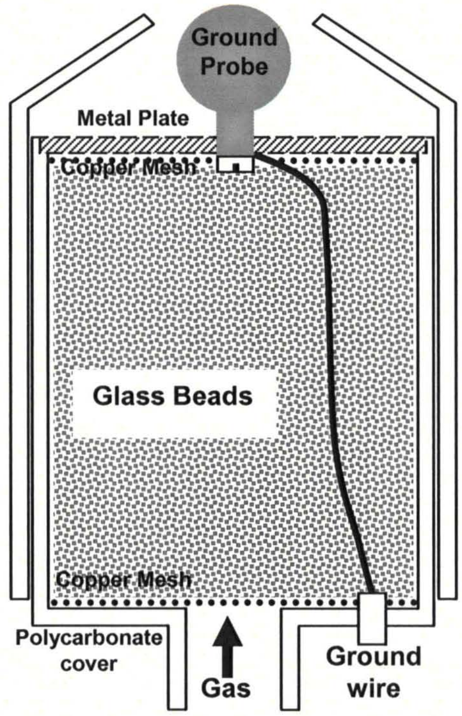
The triboelectric charge decay data match very well with corona charge decay data for a majority of the SCAPE suit materials. The lone exceptions would be the Trellchem VPS White and the Saint Gobain materials at high humidity. However, this is more likely a result of the pass/fail criteria for each test. If the triboelectric test was less stringent, perhaps these materials would pass the test and vice-versa for the corona charge decay measurements. In either case, the decay times are very similar.

The best material to use would be Trellchem VPS followed by the Saint Gobain, Trellchem HPS, Respirex and Reeves according to the results of both charge decay tests. However, it is not completely clear that any charge deposited onto the surface of these materials could result in an ignition of a flammable gas which is of prime concern for workers wearing SCAPE suit materials. To answer this question requires Spark Incendivity Testing.

4.0 Spark Incendivity Testing

If the materials fail any of the above three tests, they will be tested using Spark Incendivity Testing, a new International Standard being created by the International Electrotechnical Commission (IEC) entitled, "Electrostatic Classification of Flexible Intermediate Bulk Containers (FIBCs)"*. This test method has been successful for evaluating the safety of FIBCs which are widely used for the storage, transportation and handling of powdered, flaked or granular material throughout industry. The mishandling, improper grounding, and poor electrostatic dissipation properties of FIBCs have led to several hazardous events which have caused injury and/or death to workers in some cases.

The use of the new IEC test standard has greatly decreased the number of incidents by addressing the ESD hazard properly. Essentially the test method is to charge a material either by corona charging and/or triboelectric charging and then purposely discharge the surface of the test material (in the form of a spark) using a metal sphere while in the presence of a flammable gas mixture. If the energy of the spark has at least the energy equal to the minimum ignition energy (MIE) of the gas mixture, then the resulting discharge will be capable of igniting the gas mixture. This test method directly measures a material's propensity to extract sufficient ignitable charge from its surface when a worker and/or objects are nearby.



*International Electrotechnical Commission, "Electrostatic Classification of Flexible Intermediate Bulk Containers (FIBC) – Test Methods and Requirements", IEC 61340-4-4 (in press) (2004).

To perform this test, a Spark Incendivity Probe (SIP) is used. Gases with a known MIE enter into a polycarbonate mixing chamber full of glass beads to ensure uniform mixing and to serve as a flame arrestor to prevent back propagation. The gas mixture passes first through fine copper mesh and then into the mixing chamber before passing through a second copper mesh and a perforated metal plate. The gases then surround the brass electrode which is electrically grounded. It is here that the ignition occurs.

The proposed test standard normally calls for gas mixtures of 13% ethylene in air, which has an MIE of 0.14 mJ. This is the case for FIBC's in the presence of methanol environments as seen normally in industry. Here however, testing is performed using hydrogen in air at stoichiometric mixtures (30% H_2 and 70% dry air as before) having a much lower MIE of 0.02 mJ to represent the worst-case scenario of a charged material in the presence of a hydrogen-enriched atmosphere. Hydrogen and other flammable gases and liquids are commonly used in spaceport operations hence electrostatic charging could pose a problem if incendive discharges exist. Tribocharging exists in several forms such as charged workers, charged payloads or equipment, charged liquids and vapors during typical orbiter processing and operations. Another reason to use a stoichiometric hydrogen-air mixture is to have a safety factor of 100. This comes about since the MIE of the hypergolic fuel Monomethylhydrazine (MMH)* has been measured to be 2.8 mJ which is almost 100 times that of 30% hydrogen in air. The prime purpose of using the SCAPE suits is to protect workers from MMH and NH_4.

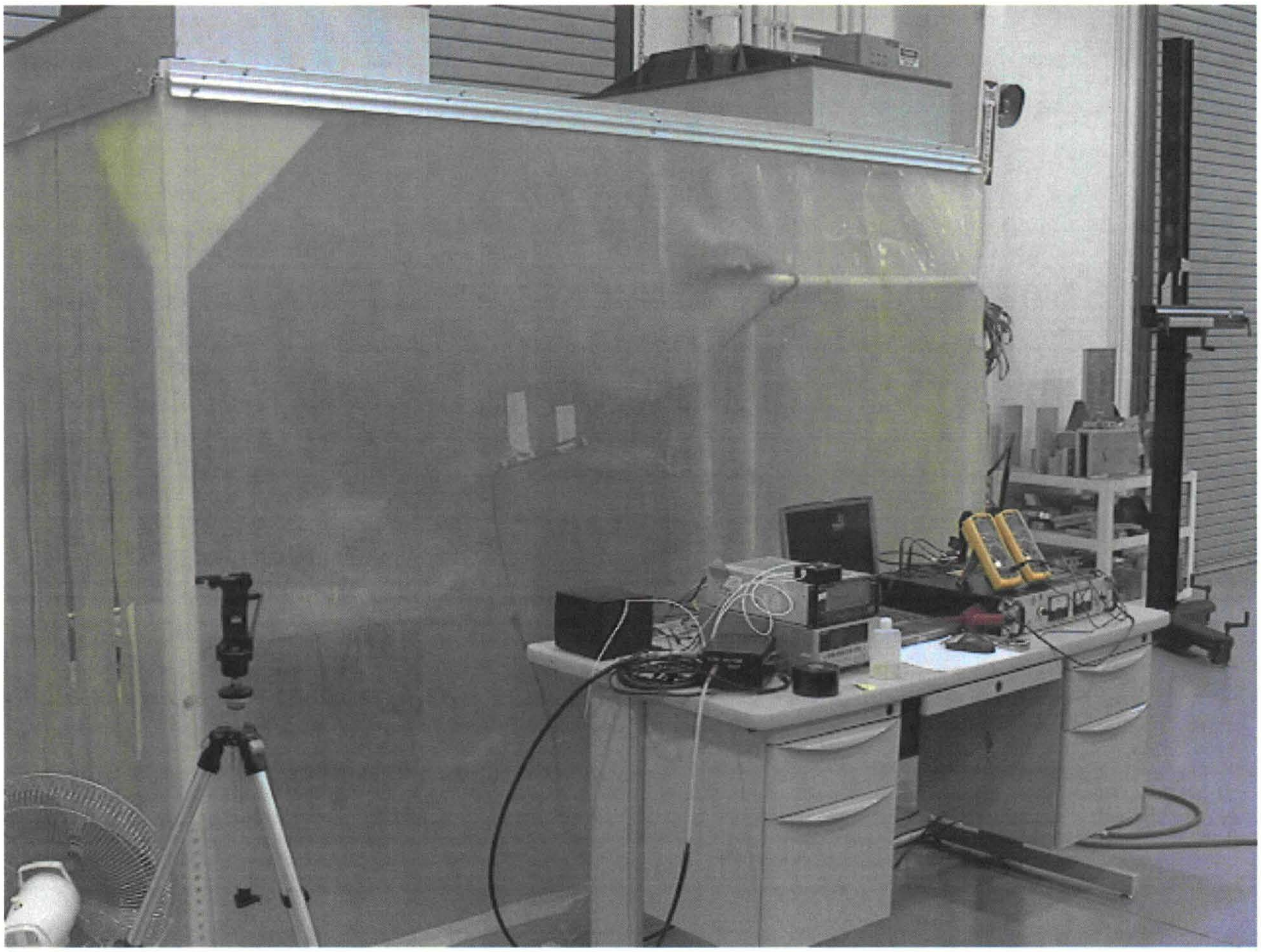
Samples are typically mounted on an insulating frame using clips. Once mounted, the materials are acclimated for up to two days at both 20% ± 5% relative humidity and 50% ± 5% relative humidity. Charge was applied to the materials in two ways. The first method is corona charging. A high-voltage power supply is connected to a corona needle plate to create ions in the air that deposit onto the surface of the test material. The voltage is set to -30kV to deposit charge levels similar to what is seen in FIBCs. The second method to apply charge to the materials is by tribocharging with wool. The wool cloth is repeatedly rubbed against the test materials until they are saturated with charge. After deposition onto the surface, the resulting surface potential is measured using a JCI 140 Fieldmeter (John Chubb Instruments) and recorded.

After the test material is fully charged, the gas mixture is allowed to flow through the probe for at least 30 seconds. The probe then approaches the charged material with the speed of approach of about (0.75 ± 0.25) m/s. Too slow an approach would cause corona to reduce local charge levels and too fast an approach would cause quenching of the nascent flame kernel. In the case that the extracted charge is sufficient to cause an ignition of the hydrogen-air mixture, the ignition event is recorded.

In some cases, a metal back plate is used for some of the corona charge applications in order to simulate a "worst case" charge scenario. It is well known that the amount charge significantly increases with the presence of a metal backing. In this case it should be easy to extract incendiary discharges. However, if incendiary discharges do not occur in the presence of a metal backing the materials could be deemed safe as is and normally do not require further testing.

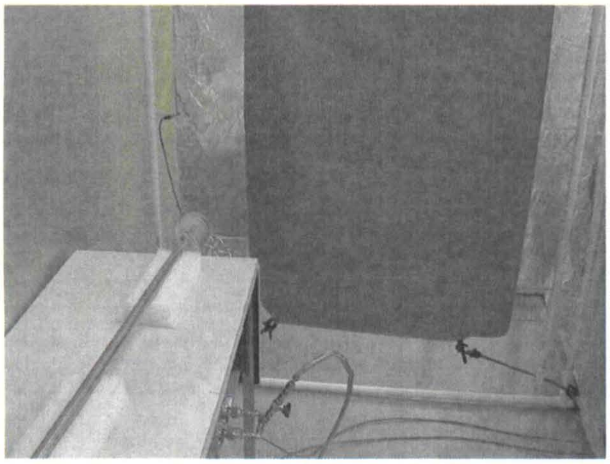
*Hornung, S.D., Davis, D.D. and Baker, D.L., "Determination of Minimum Ignition Energy for Monomethylhydrazine (MMH) and Unsymmetrical Dimethylhydrazine (UDMH)", WSTF-IR-98-0105 (1998).

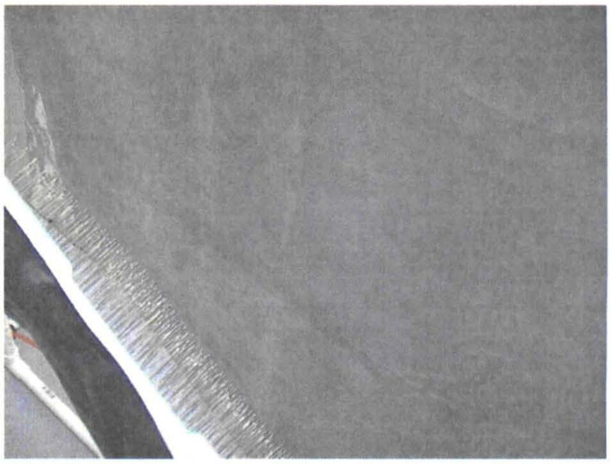
A portable clean room was refitted to house the Spark Incendivity Test Unit which was necessary to control the humidity. Dry air was fed into the volume using a large tube bank outside of the Shaker Facility part of the Cryogenics Laboratory. All of the controls for the experiments including the power supplies, hydrogen and oxygen gas monitors, the cluster controller for the mass flow controllers, the capacitor bank, and electrometers are kept outside the clean room free from the hazardous gases. Mass flow controllers are used to fix the flow rates of the hydrogen at 0.9 liters/min and air at 2.1 liters/min which provides the stoichiometric mixture.



Hydrogen is allowed to vent into the large Shaker Facility to prevent high concentrations of the flammable gas mixture. The hydrogen and oxygen concentration is monitored inside the clean room at all times. Humidity is monitored at two locations inside as well.

Two operators are required for Spark Incendivity testing. One operator performs the Spark Incendivity test while inside the clean room. The inside operator is also responsible for both corona charging and tribocharging of the test materials. The outside operator controls the voltage for the power supply for corona charging, monitors charge levels on the capacitor bank and records all spark and ignition events.





The Spark Incendivity tests are performed inside the clean room under controlled environmental conditions. The figure on the left shows the Spark Incendivity Probe lying on a table. The back of the probe is connected to two mass flow controllers that are fed from k-bottles of hydrogen and air. Flame arrestors are in place to prevent back propagation of the ignition.

The SCAPE suit test materials are mounted to the PVC frame and charged by either wool or corona charging. In some tests a metal backing was applied to increase the surface charge deposition to extremely high levels. This grounded metal backing is shown in the left figure behind the SCAPE material. The figure on the right shows the corona charging device used to supply surface charge to the materials. It is made of hundred of needles electrically connected together with a metal backing spaced at one centimeter apart. The corona charger is connected to a high voltage power supply that provides 30,000 volts of negative charge to the surface.

When the operator has finished charging the material he/she turns on the gas flow using the valve in the back of the probe and waits about 30 seconds before approaching the charged surface to allow the proper gas mixture to be present. Ignitions are monitored by listening to the loud pop sound of the hydrogen-air mixture. The violent nature of a hydrogen-air mixture is easily distinguishable from other background noise. In some cases sparks can be observed as charge travels from the sample material to the probe. After charging, the Spark Incendivity probe approaches the sample in five separate locations. Ignitions, non-ignitions and observable sparks are all recorded for every approach.

4.1 Spark Incendivity Results

a. **Trellchem VPS Type TE (no metal backing)**

N = No Ignition Y = Yes Ignition

	Corona										Tribo									
	Low Humidity (_26_%RH)					High Humidity (_50_%RH)					Low Humidity (_26_%RH)					High Humidity (_50_%RH)				
	Approach #					Approach #					Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N

Spark
Ignition

Trellchem VPS was not tested at high humidity since there were no ignitions with the metal backing as shown on the following page.

(Trellchem VPS Continued)

	Corona With Metal Backing									
	Low Humidity (__28__%RH)					High Humidity (__50__%RH)				
	Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5
1						N	N	N	N	N
2						N	N	N	N	N
3						N	N	N	N	N
4						N	N	N	N	N
5						N	N	N	N	N
6						N	N	N	N	N
7						N	N	N	N	N
8						N	N	N	N	N
9						N	N	N	N	N
10						N	N	N	N	N
11						N	N	N	N	N
12						N	N	N	N	N
13						N	N	N	N	N
14						N	N	N	N	N
15						N	N	N	N	N
16						N	N	N	N	N
17						N	N	N	N	N
18						N	N	N	N	N
19						N	N	N	N	N
20						N	N	N	N	N
21						N	N	N	N	N
22						N	N	N	N	N
23						N	N	N	N	N
24						N	N	N	N	N
25						N	N	N	N	N

Spark
Ignition

There were no ignitions of the Trellchem VPS with a metal backing at high humidity.

b. Trellchem HPS Type TE (no metal backing)

	Corona										Tribo									
	Low Humidity (26 %RH)					High Humidity (50 %RH)					Low Humidity (26 %RH)					High Humidity (50 %RH)				
	Approach #					Approach #					Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Spark
Ignition

c. Reeves SCAPE Suit Fabric (no metal backing)

	Corona										Tribo									
	Low Humidity (26 %RH)					High Humidity (50 %RH)					Low Humidity (26 %RH)					High Humidity (50 %RH)				
	Approach #					Approach #					Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Spark
Ignition

Reeves was tested at high humidity since there were ignitions with a metal backing as shown on the following page.

(Reeves Continued)

	Corona With Metal Backing									
	Low Humidity (_28_%RH)					High Humidity (_50_%RH)				
	Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5
1						N	N	N	N	N
2						N	N	N	N	N
3						N	N	N	N	N
4						N	N	N	N	N
5						N	N	N	N	N
6						N	N	N	N	N
7						N	N	N	N	N
8						N	N	N	N	N
9						N	Y	N	N	N
10						N	N	N	N	N
11						N	N	N	N	N
12						N	N	N	N	N
13						N	N	N	N	N
14						N	N	N	N	N
15						N	Y	N	N	N
16						N	N	N	N	N
17						N	N	N	N	N
18						N	N	N	N	N
19						N	N	N	N	N
20						N	N	N	N	N
21						N	N	N	N	N
22						N	Y	N	N	N
23						N	N	Y	N	N
24						N	N	N	N	N
25						N	N	N	N	N

Spark
Ignition

There were four ignitions of the Reeves material in the presence of a metal backing.

d. Respirex (with no metal backing)

	Corona										Tribo									
	Low Humidity (_28_%RH)					High Humidity (_50_%RH)					Low Humidity (_28_%RH)					High Humidity (_50_%RH)				
	Approach #					Approach #					Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N						N	N	N	N	N	N	N	N	N	N

Spark
Ignition

Respirex was not tested at high humidity since there were no ignitions with the metal backing as shown on the following page.

(Respirex Continued)

	Corona With Metal Backing									
	Low Humidity (28 %RH)					High Humidity (50 %RH)				
	Approach #					Approach #				
Run #	1	2	3	4	5	1	2	3	4	5
1						N	N	N	N	N
2						N	N	N	N	N
3						N	N	N	N	N
4						N	N	N	N	N
5						N	N	N	N	N
6						N	N	N	N	N
7						N	N	N	N	N
8						N	N	N	N	N
9						N	N	N	N	N
10						N	N	N	N	N
11						N	N	N	N	N
12						N	N	N	N	N
13						N	N	N	N	N
14						N	N	N	N	N
15						N	N	N	N	N
16						N	N	N	N	N
17						N	N	N	N	N
18						N	N	N	N	N
19						N	N	N	N	N
20						N	N	N	N	N
21						N	N	N	N	N
22						N	N	N	N	N
23						N	N	N	N	N
24						N	N	N	N	N
25						N	N	N	N	N

Spark
Ignition

There were no ignitions of the Respirex materials with a metal backing.

e. Saint Gobain (no metal backing)

	Corona						Tribo					
	Low Humidity (_26_%RH)			High Humidity (_50_%RH)			Low Humidity (_26_%RH)			High Humidity (_50_%RH)		
	Approach #			Approach #			Approach #			Approach #		
Run #	1	2	3	1	2	3	1	2	3	1	2	3
1	N	N	N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N	N	N	N	N	N	N	N

Spark
Ignition

There were no ignitions of the hydrogen-air mixture for any of the tests using the *bare* SCAPE materials. The only sparks and ignitions recorded were for the metal-backed case during corona charging. Thus the materials themselves should not be able to generate sparks of sufficient energy to ignite hypergols provided they do not have a metallic backing since they were unable to ignite an easily ignitable hydrogen-air gas mixture.

Spark Incendivity tests were then performed on Reeves materials with embedded ground wires and fibers to see if they posed the same hazard as materials backed with a solid metal backing.

f. Scape Suit fabric with Embedded Grounding Wire

	Corona						Tribo					
	Low Humidity (_26_%RH)			High Humidity (_50_%RH)			Low Humidity (_26_%RH)			High Humidity (_50_%RH)		
	Approach #			Approach #			Approach #			Approach #		
Run #	1	2	3	1	2	3	1	2	3	1	2	3
1	N	N	N	N	N	N	N	N	N	N	N	N
2	N	N	N	N	N	N	N	N	N	N	N	N
3	N	N	N	N	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	N	N	N	N	N	N
5	N	N	N	N	N	N	N	N	N	N	N	N
6	N	N	N	N	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N	N	N	N	N
10	N	N	N	N	N	N	N	N	N	N	N	N
11	N	N	N	N	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N	N	N	N	N
16	N	N	N	N	N	N	N	N	N	N	N	N
17	N	N	N	N	N	N	N	N	N	N	N	N
18	N	N	N	N	N	N	N	N	N	N	N	N
19	N	N	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	N	N	N	N	N	N
21	N	N	N	N	N	N	N	N	N	N	N	N
22	N	N	N	N	N	N	N	N	N	N	N	N
23	N	N	N	N	N	N	N	N	N	N	N	N
24	N	N	N	N	N	N	N	N	N	N	N	N
25	N	N	N	N	N	N	N	N	N	N	N	N

Spark
Ignition

g. Scape Suit fabric with Embedded Grounding Fibers

	Corona				Tribo			
	Low Humidity (_26_%RH)		High Humidity (_50_%RH)		Low Humidity (_26_%RH)		High Humidity (_50_%RH)	
	Approach #		Approach #		Approach #		Approach #	
Run #	1	2	1	2	1	2	1	2
1	N	N	N	N	N	N	N	N
2	N	N	N	N	N	N	N	N
3	N	N	N	N	N	N	N	N
4	N	N	N	N	N	N	N	N
5	N	N	N	N	N	N	N	N
6	N	N	N	N	N	N	N	N
7	N	N	N	N	N	N	N	N
8	N	N	N	N	N	N	N	N
9	N	N	N	N	N	N	N	N
10	N	N	N	N	N	N	N	N
11	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N
16	N	N	N	N	N	N	N	N
17	N	N	N	N	N	N	N	N
18	N	N	N	N	N	N	N	N
19	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	N	N
21	N	N	N	N	N	N	N	N
22	N	N	N	N	N	N	N	N
23	N	N	N	N	N	N	N	N
24	N	N	N	N	N	N	N	N
25	N	N	N	N	N	N	N	N

Spark
Ignition

The Reeves materials with embedded fibers or wires did produce any incendive events are should be deemed safe to use as is.

4.2 Summary of Spark Incendivity Test Results

No ignitions were detected in any of the SCAPE suit materials. Ignitions were detected with the Reeves material in the presence of a metal backing during corona charging. The materials by themselves, without the presence of a metal surface in the interior of the suit, should not produce any sparks with enough energy to ignite hypergols.

Tests were then performed on the Reeves materials that sparked with embedded grounded wires. No ignitions were detected in this case.

5.0 Conclusions

The nine materials received underwent extensive testing in our laboratory. The testing included Surface and Volume resistance measurements, Corona Charge Decay, Triboelectric Charge Decay, and Spark Incendivity Tests.

Section 1.4 summarizes the results of the Surface and Volume Resistance measurements. According ton ANSI ESD Standards, with two exceptions, all of the SCAPE materials are insulators and should not dissipate electrostatic charge to ground. The two exceptions were the main part of the boot and the main part of the glove, which were found to be statically dissipative. However, the top bands of both glove and boot were insulative.

Section 2.2 summarizes the results of the Corona Charge Decay tests. The Reeves, Trellchem HPS, Trelchem VPS, Respirex, and Saint Gobain were tested on both sides. The tests showed that, with two important exceptions, these materials did not dissipate charge to ground and failed the Corona Charge Decay test. One exception was the Trellchem VPS, which passed the Corona Charge Decay tests on both sides at room humidity and at low humidity, even though the resistance measurements for both sides of this material classify it as insulative. The second exception was the Saint Gobain material, which dissipated the charge in 0.2 seconds at room humidity. However, this material fails the Corona test at low humidities.

Section 2.3 summarizes our investigation of the use of additives with Staticide. The application of Staticide alone is sufficient to bring the charge decay times into acceptable limits; that is, decay times to 1/e in less than 1 second. The application of Staticide-Dawn mix (5 parts of Dawn to 100 parts of Staticide) 24 hours after preparation produces significantly better charge decay properties that Staticide alone applied 24 h in advance. Using Isopropyl Alcohol as an additive to Staticide has no significant effect on the decay properties.

Section 3.2 shows that the results of the Triboelectric Charge Decay Tests for the most part agree with the results of the Corona Charge Decay tests.

According to the Corona and Triboelectric Charge Decay Tests alone, the best materials to use are Trellchem VPS and Saint Gobain, Trellchem HPS, Respirex, and Reeves.

However, the crucial test is the Spark Incendivity Test. This test provides information on the ability of an electrostatically charge material to ignite a flammable gas when a spark is drawn from the material. Section 4.2 summarizes the result of that important test. No SCAPE suit material by itself ignited in the presence of a flammable atmosphere.

To simulate a worst-case discharge event, a metal sheet is placed behind the material to be tested. In this case, the material is able to charge to much higher levels, creating the possibility of spark discharges of higher energies. If the materials do not ignite in this worst-case situation, they are considered safe and no further tests are required. All of the SCAPE suit materials tested in this fashion passed this more stringent test, with one exception: the Reeves materials.

We then proceeded to perform the Spark Incendivity Test on the Reeves materials with embedded wires No ignitions were detected in this case and the Reeves materials were considered to be safe when used in this fashion.

Charles R. Buhler, Ph.D.
Physicist, ASRC Aerospace
NASA Electrostatics and Surface Physics Laboratory

Carlos I. Calle, Ph.D.
Lead Scientist, NASA Electrostatics and Surface Physics Laboratory
YA-C2-T
Kennedy Space Center, FL 32899